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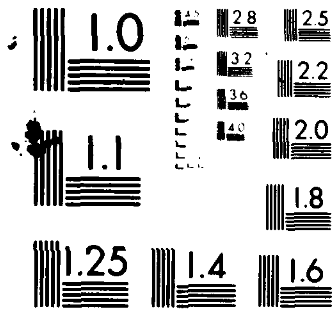

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DESCRIBING THE REPRESENTATION OF DECISION PROBLEMS:
AN APPLICATION OF MULTIDIMENSIONAL SCALING
AND CLUSTER ANALYSIS

CAROL MANNING

TR 15-12-81 DECEMBER 1981

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The purpose of this study was to describe the important representations for an example of a common class of decision problems, facing a shortage of a commodity. Describing potential problem representations is important because decision problems are typically ill-structured ~~(Taylor, 1974)~~, and a decision maker's representation of a problem is not obvious to the experimenter. Describing the dimensions along which a group of subjects judged the similarity of potential solutions to a problem should give insight into various ways in which the problem may be represented. This will provide a

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basis for additional research on the processes involved in the generation of act solutions and their associated outcomes.

Multidimensional scaling and cluster analysis were used to analyze the similarity of 43 acts suggested to solve the parking problem at the University of Oklahoma. In Experiment 1, sixty subjects rated the similarity of a set of randomly chosen act pairs. The similarity judgments were averaged across subjects and submitted to the ALSCAL procedure of SAS. A three-dimensional solution was identified as most appropriate. In Experiment 2, fifty subjects rated randomly chosen subsets of the same acts on twelve bipolar scales which represented potential ways of representing a problem. Three scales suggested generic strategies for solving the problem. Four scales suggested problem-solving strategies specific to the parking problem. One scale suggested a personal goal which might be fulfilled by employing an action. Four scales were potential measures of the acts' utility. The scale ratings obtained in Experiment 2 were averaged across subjects, then regressed on the three-dimensional solution derived from multidimensional scaling to objectively describe the dimensions. The three dimensions were found to most closely resemble specific strategies for solving the parking problem. Dimension 1 was identified as "involves alternate forms of transportation". Dimension 2 was identified as "involves rescheduling activities" and "changes current priorities". Dimension 3 was identified as "requires building new facilities".

Hierarchical cluster analysis was used to analyze the similarity judgments to examine neighborhoods of acts in the three-dimensional space to determine whether an alternative interpretation of the relationships between acts might be obtained. Seven clusters were identified. Four clusters were specific instances of a more general category "increase the amount of space available". Another cluster was the category "involves alternate forms of transportation". Two other clusters involved rescheduling activities and enforcing current parking regulations more strictly.

The three dimensions derived from multidimensional scaling and the set of clusters obtained from cluster analysis seem to describe alternative strategies for solving the parking problem from which individual decision makers might sample when representing the problem. Although in real-world decision problems the problem space is unstructured, these results suggest that a limited number of constructs may sufficiently describe the important problem representations decision makers employ to interpret a problem.

Abstract

The purpose of this study was to describe the important representations for an example of a common class of decision problems, facing a shortage of a commodity. Describing potential problem representations is important because decision problems are typically ill-structured (Taylor, 1974), and a decision maker's representation of a problem is not obvious to the experimenter. Describing the dimensions along which a group of subjects judged the similarity of potential solutions to a problem should give insight into various ways in which the problem may be represented. This will provide a basis for additional research on the processes involved in the generation of act solutions and their associated outcomes.

Multidimensional scaling and cluster analysis were used to analyze the similarity of 43 acts suggested to solve the parking problem at Oklahoma University. In Experiment 1, sixty subjects rated the similarity of a set of randomly chosen act pairs. The similarity judgments were averaged across subjects and submitted to the ALSCAL procedure of SAS. A three dimensional solution was identified as most appropriate. In Experiment 2, fifty subjects rated randomly chosen subsets of the same acts on twelve bipolar scales which represented potential ways of representing a problem. Three scales suggested generic strategies for solving the problem. Four scales suggested problem-solving strategies specific to the parking problem. One scale suggested a personal goal which might be fulfilled by employing an action. Four scales were potential measures of the acts' utility. The scale ratings obtained in Experiment 2 were averaged across subjects, then regressed on the three dimensional solution derived from multidimensional scaling to objectively describe the dimensions. The three dimensions were found to most closely resemble specific strategies for solving the parking problem. Dimension 1 was identified as "involves alternate forms of transportation". Dimension 2 was identified as "involves rescheduling activities" and "changes current priorities". Dimension 3 was identified as "requires building new facilities".

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Describing the representation of decision problems: An application of multidimensional scaling and cluster analysis

Taylor (1974) distinguished between well-defined problem situations in which the current state of the problem solver, the desired goal state and the operations used to solve the problem are specified, and ill-defined problem situations in which the current state, the goal state and permissible operations are not specified. Studies of human problem solving have traditionally examined structured problems, i.e., the current problem state, the goal state and the permissible operations to solve the problem are defined in advance to the subject. For example, the problem state for the Towers of Hanoi problem used by Simon and Hayes (1976) is a particular ordering of different sized disks on one peg and two adjacent empty pegs. The goal state is the same ordering of the disks on one of the other pegs. Permissible operations used to move the disks are specified before the subject attempts to solve the problem. The experimenters infer the strategies subjects employ to solve the problem by observing the combinations of permissible operations used to move from the problem state to the goal state.

A comparable investigation of strategies and processes involved in decision making is complicated by the ill-defined structure associated with most decision problems. Decision making can be characterized as choosing an action which is likely to achieve the goal state of solving a decision problem. Most decision problems are more complex than the tasks studied in the problem-solving literature; decision problems do not typically have well-defined problem and goal states, and rarely are the operations which would solve a real-world decision problem well-defined. We must first understand how decision makers define the problem and goal states for a problem before investigating how they process information and employ problem solving strategies to transform the problem state into the goal state.

<u>Predecision processes in decision making.</u> The processes involved in choosing an action to solve a complex decision problem are of interest to decision theorists, but cannot be easily investigated because the decision makers' interpretation of the problem state, the goal state and the operations which will move the decision

maker from the problem state to the goal state are typically not well-defined or immediately obvious to the experimenter. Predecision processes should involve identification of the relevant components of a decision problem which might influence the probability of successfully solving it. Decision components may include acts, which are potential solutions to a problem, hypotheses about states of the world or situational conditions which might influence the outcome resulting from implementation of an act, and outcomes or consequences which might be associated with each act. The decision maker may also estimate probabilities of occurrence of the identified outcomes and utilities associated with each outcome. These decision components should be evaluated and combined to determine the choice of an alternative.

Several studies have investigated the process of hypothesis generation (see Gettys, Manning, Mehle and Fisher, Note 1, for an overview of this research). Recently, the process of act generation has been investigated (Pitz, Sachs and Heerboth, 1980; Gettys, Manning and Casey, Note 2). These studies primarily described the quality of subjects' performance in tasks which elicited act solutions. Before studying more extensively the processes which occur in act generation, a preliminary study seems warranted which will allow the description of potential representations of the problem state that decision makers may employ when generating acts to solve the problem.

In the current study, a problem was used which belongs to a common class of decision problems, facing a shortage of a commodity. The specific problem used involved the shortage of parking places at the University of Oklahoma. Before considering how decision makers process information about the parking problem to generate act solutions, it would be useful to understand how they represent and interpret the problem.

<u>Ways to measure problem representation.</u> The goal of this study was to shed light upon potential ways of representing a problem by identifying the important dimensions which describe how subjects represent a set of acts suggested to solve a problem. An investigation of problem representation should identify decision makers' strategies for interpreting a problem rather than confirming the experimenters' preconceived ideas about the way the problem is structured. Carroll (1980) observed that much of the research on decision making has a

confirmation bias because it is designed to match current theories rather than discover the strategies decision makers' employ. We wish to avoid making the mistake of performing research on problem representation which confirms our presuppositions. To objectively assess problem representation, a study seems warranted which will describe the dimensions of a common decision problem which seem important to a group of subjects. Later studies may build on this framework by determining why an individual decision maker adopts a specific problem representation or by manipulating the problem representation a decision maker adopts.

It is difficult to study problem representation because we cannot directly observe the process. Representing a decision problem does not typically involve emitting a response. Thus, the study of problem representation must proceed indirectly by either examining a response a decision maker does not typically emit or by inferring that a response not directly related to the representation of the problem suggests a specific problem representation was employed.

Taking the approach of examining a response not typically emitted by a decision maker, one might present subjects with a problem and ask them to describe their representation of it. The most sophisticated form of this type of research is called protocol analysis (Newell and Simon, 1972). Protocol analysis is used to describe processes which occur in problem-solving by obtaining subjects' verbal reports emitted while performing a problem-solving task. Simon and his associates primarily use protocol analysis to investigate the processes involved in solving structured problems (Simon, 1975; Simon and Hayes, 1976) Payne, Braunstein and Carroll (1978) have examined the processes involved in making choices in less well-structured problem situations with protocol analysis.

Using protocol analysis requires asking subjects to describe cognitive processes which are not typically verbalized. A procedure of this type might not successfully describe problem representation if subjects' verbalization of the process alters their problem representation. Furthermore, Nisbett and Wilson (1977) presented evidence which suggests that subjects may not have valid insight into their own cognitive processes. Smith and Miller (1978) argued that this conclusion should be modified; subjective reports may be useful in some situations. They suggested that protocol analysis may be useful in

problem-solving situations in which the problems are unfamiliar. Thus, protocol analysis may provide some insight into the representation of decision problems. However, other techniques of describing potential problem representations may also be useful.

Another way to study problem representation is to examine responses indirectly related to the representation of a problem and to infer from these responses that a particular problem representation was employed. Cognitive psychologists investigating subjects' representation of prose passages have taken this approach. Several studies have employed nonmetric multidimensional scaling to make inferences about subjects' internal representation of a story. Nonmetric multidimensional scaling (nonmetric MDS) uses estimates of the psychological distance between stimuli, such as subjects' judgments of the similarity of pairs of stimuli, to produce a multidimensional space. The stimuli are displayed in the space as points having coordinate locations. The space may contain as many dimensions as are important for describing the criteria subjects used to make the similarity judgments.

Bisanz, LaPorte, Vesonder and Voss (1978) used nonmetric MDS to describe subjects' representations of the thematic relationships between stimuli embedded in stories. LaPorte and Voss (1979) used nonmetric MDS to describe subjects' representations of the relationships between stimuli before and after they were related in the context of a story.

Nonmetric multidimensional scaling might also be profitably used to describe decision makers' representations of decision problems. MDS requires an estimate of psychological distance between stimuli which are relevant to the problem. For this study, acts suggested to solve a problem comprise a relevant response typically emitted by decision makers. These responses are indirectly related to problem representation, because the way a decision maker represents a problem may influence the acts generated. Judgments of the similarity of pairs of acts are estimates of psychological distance typically used in a multidimensional scaling study to create a psychological space. Similarity judgments may also be indirectly related to problem representation because comparing pairs of acts may also be influenced by the way the decision maker represents the problem.

In this study, judgments of the similarity of acts suggested to solve one instance of the shortage problem were obtained from subjects and analyzed with multidimensional scaling and hierarchical cluster analysis. The similarity judgments were first analyzed using nonmetric MDS to produce a space in which the acts were displayed on a number of dimensions which described the criteria subjects employed when making the similarity judgments. To objectively describe the identities of the dimensions isolated by multidimensional scaling, a set of ratings for each act on several descriptive scales was obtained from a different group of subjects. The ratings were based on the degree to which a set of bipolar scales described individual acts. The bipolar scales reflected potential problem representations the subjects might have considered when assessing the acts′ similarity. The ratings on the set of bipolar scales were regressed on the acts′ stimulus coordinates in the multidimensional space to determine whether any of the scales could be described by the dimensions in the multidimensional space. Regressing the scale ratings for each act onto the stimulus coordinates provides an objective method for describing the criteria subjects used to judge the similarity of acts. Because the similarity judgments of acts should be related to the way decision makers represent a problem, the interpretation of the important dimensions derived from MDS may shed light on important problem dimensions which may be employed.

Hierarchical cluster analysis is a different statistical technique which complements the MDS results by forming neighborhoods in the multidimensional space in which the most similar acts reside. Shepard (1974) showed that examining hierarchical clusters imposed on a two dimensional space derived from MDS provided additional insight into interpreting judged relationships of similarity between animals. Examining neighborhoods of similar acts in the multidimensional space rather than the acts′ relative locations along a set of dimensions may provide another method to assess the criteria subjects use when judging similarity and thus suggest how decision makers may represent a problem.

<u>Possible problem representations.</u> The current study examines how a group of decision makers represents the parking problem, one instance of a more general problem of facing a shortage of a commodity. The questions to be answered by this study are 1) Is problem representation unidimensional or multidimensional? and 2)

What types of dimensions might decision makers use to represent a problem? The first question deals with the issue of whether a problem can be interpreted from more than one perspective. It is possible that all decision makers represent the parking problem, and other shortage problems, along a single dimension. If this hypothesis is true, then problem representation would be the same for all decision makers, and the task of discovering the processes involved in act generation would be much simpler. Multidimensional scaling allows the determination of the number and identity of important dimensions which influence the judgments of similarity made by subjects. Thus, the results of this study should suggest whether more than one representation of the parking problem might be salient to subjects.

Regardless of whether decision makers use more than one dimension when judging the similarity of acts related to the parking problem, it should be interesting to describe the form the possible representation or representations may take. For example, decision makers might consider the parking problem to be a special case of the problem of facing a shortage of any commodity. If this is true, they might represent acts to solve the parking problem according to generic strategies which might solve any instance of the shortage problem, such as "increase the supply", "reduce the demand", or "use available resources more effectively." Alternatively, decision makers might represent the problem using specific problem-solving strategies relevant to the parking problem. Another way decision makers could represent the parking problem might relate to the interpretation of the goal state determined by the desirable outcomes for the problem. For example, if the decision makers dealing with the parking problem plan to increase enrollment, they might represent the problem differently than if their major goals were to reduce spending.

To determine whether any of the ways of representing a problem mentioned above were used by subjects when judging the similarity of acts, the acts were rated on a set of bipolar scales which described various potential problem representations decision makers might consider when evaluating acts. These ratings may be regressed against the stimulus coordinates of the acts in the derived space. The results will suggest which characteristics, if any, describe the dimensions derived from the multidimensional scaling study. The description of the

experiments in which the similarity judgments and ratings of acts on bipolar scales were obtained will now be presented.

Methods used to obtain similarity judgments.

The current study employed act stimuli obtained from a previous experiment. This section provides a synopsis of the methods used in the earlier experiment to obtain a set of acts suggested by subjects to solve a problem. These stimuli were a subset of a complete set of acts suggested by subjects who participated in the earlier experiment. For a more complete description of the method for obtaining the act stimuli, see Gettys, Manning and Casey (Note 1).

Compilation of act stimuli. Acts used in this study were obtained from thirty subjects who read the problem shown below:

PARKING

> It is difficult to find a place to park at OU. Although approximately 21,000 students are enrolled and about 3500 faculty and staff are employed, about half that many parking spaces are available.
>
> There are 6850 parking places available on campus for faculty/staff, commuters, housing, Law, and OCCE. The Lloyd Noble Center provides an additional 3500 spaces, yielding a total of 10,350. One space for every two people doesn't sound too bad, but anyone who has tried to find a parking space at 9:00 a.m. knows this is a real problem.
>
> Suppose you are a member of a student organization which is researching this problem for officials of the University. Your task is to suggest as many possible solutions to the committee as you can. These solutions need not be "perfect"; often good solutions are derived from ideas which at first seem silly. The University officials will worry about how to pay for any solutions suggested and how to convince the involved parties to accept the decision. Your task is simply to think of all possible solutions which might be effective.
>
> It is important for you to enter all options which occur to you. This is similar to "thinking out loud." We do not want you to censor your options and only enter the ones which you think are particularly good. Put down all options which occur to you, good or bad. Your score in this experiment is determined by the number of options you generate, not how good they are.

The "Parking problem" was used because it is a problem familiar to our subjects, who were undergraduate psychology students. The problem also represents one instance of the more general shortage problem described in the introduction.

Subjects generated acts by entering them one at a time into a computer. The resulting set of acts was pooled, then tabulated by the experimenters; subjects suggested a total of 335 acts. Some of the 335 acts suggested were equivalent or essentially equivalent (e.g. "build a ten-story parking garage", "build a two-story parking garage"). To reduce the act set to a more manageable size, three experimenters combined the acts they considered equivalent. Acts judged to be equivalent by all three judges were classified together. The resulting set contained 170 unique acts. This set of acts was still unmanageable due to its size, so a second process was employed to further reduce the size of the set. Because the subjects were instructed to respond with everything that came to mind, the original act set contained many acts which would be unlikely to solve the parking problem (e.g. "issue everyone a pair of wings"). It seemed unnecessary to include such frivolous acts in further analyses, so an independent group of subjects reduced the set of unique acts by evaluating their quality. Thirty additional subjects decided whether taking each unique act would leave the university better off than it is now. At least 50% of the subjects thought 57 of the unique acts were of positive utility. The experimenter then reduced the act set from 57 to 43 for the multidimensional scaling experiment because fourteen of the 57 positive utility acts were very similar to others in the set. A short description of the 43 remaining acts can be found in Table 1. The acts included in Table 1 are condensed from subjects' responses.

The 43 acts described above were the stimuli for another set of subjects who judged their similarity in the present experiment.

Experiment 1.

Method

Subjects. Subjects were sixty introductory psychology students who chose to participate in the experiment to satisfy course requirements.

Obtaining similarity judgments. The method of paired comparisons (Torgerson, 1958) was employed to elicit subjective estimates of the similarity of acts. Subjects read a pair of acts then rated its similarity on a scale ranging from 1 to 10 where 1 was labelled "very similar" and 10 was labelled "very dissimilar".

Table 1
Condensed descriptions of 43 act stimuli for which similarity judgments were obtained

1. Build a high-rise parking garage.
2. Put signs up on streets around campus so they can be used for parking.
3. Repaint lines in parking lots, decreasing width.
4. Encourage carpooling by commuters.
5. Advertise advantages of riding bike or motorcycle to school.
6. Make faculty, staff park at the Lloyd Noble basketball stadium located off campus.
7. Have more of a selection of afternoon and evening courses available.
8. Don't have so many no parking zones.
9. Use extra areas around the fraternities as overflow lots.
10. Expand the parking facility at the Lloyd Noble center.
11. Encourage people not to bring their cars to school.
12. Provide greater incentives for people participating in carpools.
13. Impound cars which don't have proper parking stickers.
14. Build bicycle paths.
15. Provide more security for bicycles.
16. Use church parking lots.
17. Make some faculty parking student parking.
18. Build more parking lots.
19. Set up rapid transit system to operate during school hours.
20. Raise parking fees and improve lots currently used.
21. Put more "small car" spaces in student lots.
22. Use some OU vehicle parking for students.
23. Let people park on South Oval (grassy area centrally located).
24. Build a new lot by the jock dorms.
25. Build another lot like the one at Lloyd Noble containing 5000 spaces.
26. Build new buildings as high rises, build parking area around bottom.
27. Ask commuters to carpool.
28. The university could set up a carpool.
29. Encourage students to stop air pollution by not driving.
30. Counsel students about the parking problem.
31. Arrange for parking at Stubbeman Village (small shopping center).
32. Divert commuters to Lloyd Noble and have them take trolley to campus.
33. Have university employees park at Lloyd Noble and use trolley.
34. Have bus system from campus to shopping malls, other areas in Norman.
35. Build lots at different locations around Norman, shuttle drivers in.
36. Improve the trolley and CART systems (Campus Area Rapid Transit).
37. Form cycling clubs for commuters.
38. Staff parking needs more closely allotted times.
39. Make enough parking spaces for everyone living in dorms.
40. Make it mandatory for fraternity members to park at their houses.
41. Search for an area around campus instead of building more buildings.
42. Remove 30 minute meters from parking areas.
43. Make all commuter parking at the Lloyd Noble Center.

Assigning act pairs to subjects. Subjects could not be expected to evaluate the entire set of 903 possible act pairs. If subjects require 20 seconds to make each comparison, they would have taken approximately 5 hours to complete the task. Thus, it was more practical for subjects to evaluate only part of the matrix of act pairs. Several methods are available for obtaining similarity judgments for incomplete designs using selected subsets of the stimuli (Graef and Spence, 1979; MacCallum, 1979; Rao and Katz, 1971; Spence, in press). Graef and Spence (1979) presented Monte Carlo research which suggested that not all stimulus pairs need be present if the experimenter carefully chooses a subset of the data including stimuli which produce large-distance comparisons. However, recovery of structure for data obtained from subjects is better if all cells of the similarity matrix contain approximately equal numbers of judgments, regardless of whether subjects judged the same subsets of acts (Null, Note 3). Each subject judged a sample of 105 act pairs randomly chosen from the 903 possibilities. The randomization was done so that approximately equal numbers of judgments were obtained for each pair. The order in which each act of the pair was presented to subjects was random. Finally, individual judgments of the act pairs were averaged over the number of subjects who judged each pair to form a group matrix.

Procedure. Subjects were seated in front of a CRT terminal. First, subjects read the same version of the Parking problem shown above. Before judging the acts, subjects read the list of the 43 stimuli. Reading the complete set of acts before judging them reduced the tendency for subjects to change the value of their subjective similarity ratings as they encountered new stimuli. It also encouraged subjects to employ similar rating scales regardless of the subset of act pairs they judged.

After reading the list of stimuli, subjects read the following instructions: "Your task in this experiment is to determine the similarity of pairs of actions like the ones you see above. Your judgment of similarity should be based on your feelings of how related the actions are. The experimenter will not suggest to you how to determine the degree of similarity; you must make your own decision. You will rate the similarity of pairs of actions on a scale which will be presented on the screen. Small numbers on the scale represent a high degree of similarity,

while large numbers represent a small degree of similarity." Small numbers were assigned to very similar acts because they suggested the acts were close together while large values assigned to very dissimilar acts suggested the acts were located far away from each other.

The cursor of the CRT terminal was initially positioned in the center of the scale. Subjects judged the similarity of the 105 randomly chosen act pairs by moving the cursor of the CRT terminal left or right along the scale by holding down one of two keys on the keyboard. The judgment could be modified until the subject was satisfied. Pressing another key recorded the rating.

Deriving an act space with multidimensional scaling.

Nonmetric multidimensional scaling is a method which can be used to represent subjects' assessments of the relationships between items along dimensions. Nonmetric MDS utilizes subjective distance estimates measured on an ordinal scale to create a space in which items are located according to coordinate positions along a determined number of dimensions. MDS algorithms place the points which represent the stimuli in a space of specified dimensionality in such a way that distances between the points correspond as closely as possible to the estimates of psychological distance provided by the subjects. In this experiment, judgments of the similarity of acts were used as estimates of psychological distance. Multidimensional scaling placed acts in a 3-dimensional space such that similar acts were close together and dissimilar acts were far apart. The MDS-derived distances will not exactly correspond with subjects' distances unless the space is allowed to retain a dimensionality of one dimension less than the total number of stimuli. However, if that were allowed in this experiment, a 42-dimensional space would result. A psychological space of such dimensionality is impossible to visualize and equally difficult to interpret because each dimension must represent a distinct attribute along which stimuli may be compared. The experimenter generally strives to choose a dimensionality which accounts for the majority of the variability in the data, yet which can be easily interpreted, usually two or three dimensions (Shepard, 1974).

The derived dimensions represent the distinct bases for comparison the group of subjects employed when they evaluated the items' similarity. The number of

dimensions chosen should logically explain the group's evaluation of stimuli and should also allow the derived distances to correspond fairly closely with the group's similarity judgments. The number of dimensions which best describes subjects' judgments of similarity cannot be determined statistically, but must be chosen subjectively by the experimenter. One way to estimate the number of dimensions is to compare goodness of fit measures, called stress (Kruskal, 1964), computed for scaling solutions for which several dimensions were specified. If stress values fail to decrease by a large amount when an additional dimension is added to the solution, then the space of smaller dimensionality is considered to be adequate. Other measures which will be described later allow the experimenter to interpret the meaning of the dimensions once the number of dimensions has been determined. When the dimensionality of the space has been chosen, the scaled items can be located in the derived space according to their relative distance along each of the dimensions subjects used when evaluating their similarity.

Analysis of similarity judgments for acts using nonmetric MDS. The similarity ratings obtained in Experiment 1 were averaged across subjects to provide a matrix of similarity ratings for the 43 acts which represented the group of subjects. The group similarity judgments were then submitted to the ALSCAL procedure of the SAS statistical package (Young and Lewyckyj, Note 4).

The first goal in multidimensional scaling is to define the number of dimensions which adequately represent the psychological space, while keeping the number sufficiently small to allow relatively simple interpretation (Shepard, 1974). To estimate the appropriate dimensionality of the act space, nonmetric multidimensional scaling solutions were derived for 2, 3, 4 and 5 dimensions. Two methods were employed to estimate the appropriate dimensionality of the act space. First, Kruskal's Formula 1 stress measures (Kruskal, 1964) were compared for each dimensional solution. The stress value for a solution containing one dimension was .449, for two dimensions stress was .287, for three dimensions stress was .204, for four dimensions stress was .164 and for five dimensions stress was .136. Figure 1 shows a plot of stress as a function of dimensionality. A slight "elbow", a change in the degree to which stress decreases as dimensionality increases (as described by Kruskal and Wish, 1978), might be interpreted as occurring at either two or three dimensions. This criterion of the

dimensionality of the space was inconclusive, suggesting that either a two or a three dimensional solution may be appropriate.

A second method for assessing the dimensionality of the psychological space can be used to determine whether a two or a three dimensional solution is more appropriate. This method involves comparing observed stress values obtained from MDS for 2-5 dimensions with a set of stress values which were generated in Monte Carlo studies for 2-5 dimensions when the true dimensionality of the space was known (Spence and Graef, 1974). The dimensionality of the observed psychological space can be inferred by comparing the observed stress values computed for dimensions 2-5 with Spence and Graef's (1974) stress values computed for dimensions 2-5 when the true dimensionality was 2, 3, 4 or 5. Spence and Graef's true dimension for which the observed stress values best matched all the generated stress values is likely to be the dimensionality of the observed space. When stress values from the current study (based on 43 stimuli) were compared with Spence and Graef's (1974) generated stress values (for 36 stimuli), a 3-dimensional solution was found to be most appropriate. Because both methods of estimating the appropriate dimensionality suggested that a 3-dimensional solution was appropriate, further analyses were performed using a 3-dimensional act space.

Multidimensional scaling algorithms define a spatial solution for stimuli by rearranging stimuli in the n-dimensional space to minimize the error between the distances in the space and the psychological distances defined by the similarity judgments. This process is done iteratively, and continues until the decrease in the error between iterations is less than a criterion amount. Sometimes the multidimensional scaling algorithm finds local minima--points where the error cannot be reduced substantially between iterations but the optimal solution has not been achieved. This condition is likely to yield an uninterpretable solution with an unacceptably high stress value (Kruskal and Wish, 1978). To avoid this problem, several scaling solutions should be obtained. One way to insure against obtaining only local minima is to use different starting or initial configurations. An initial configuration defines the original placement of stimuli before they are iteratively rearranged to maximize the relationship between the distances between points in the space and the distance estimates based on subjects' similarity judgments. For this study, several kinds of initial

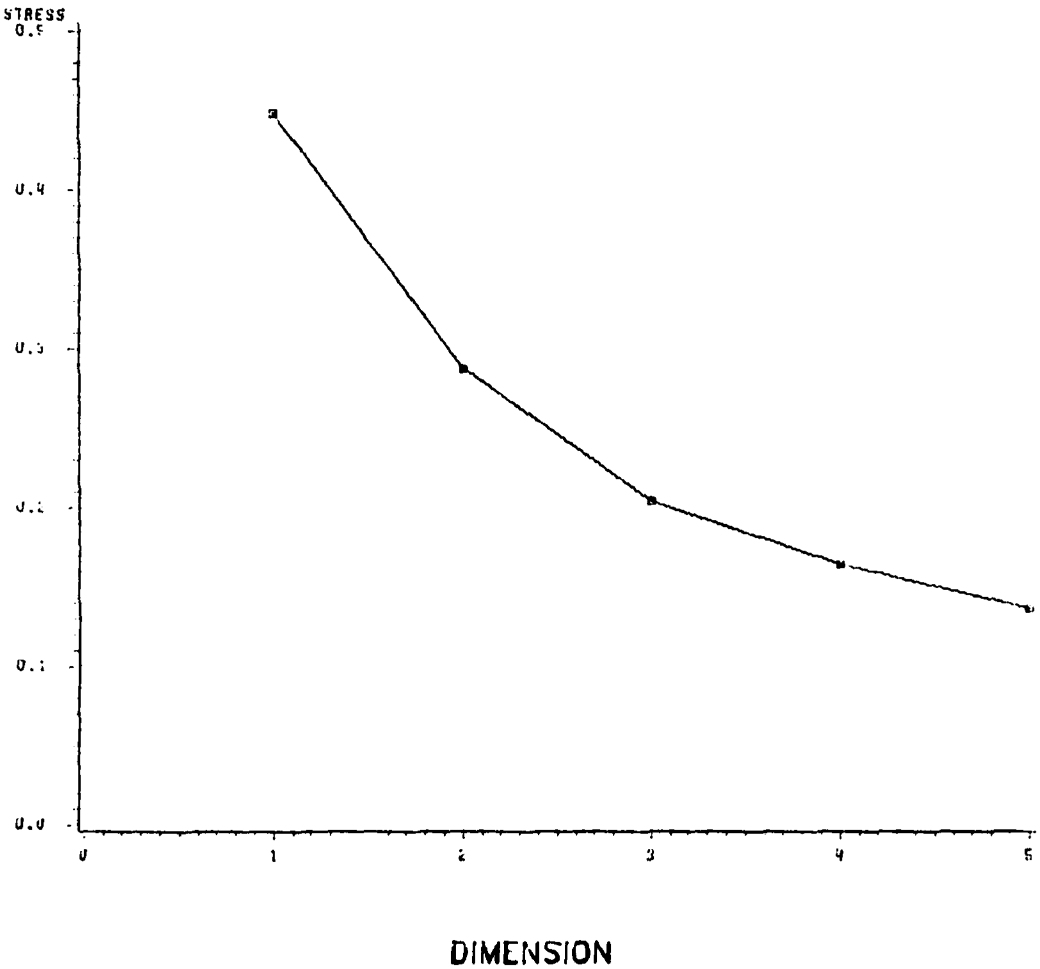

FIGURE 1. STRESS PLOTTED AGAINST DIMENSIONALITY

configurations were employed to assess the stability of the derived solution. The experimenter defined two initial configurations which were submitted to ALSCAL. Another initial configuration used was the metric solution for the same stimuli. (A metric solution assumes the data were measured on an interval scale). Several ALSCAL-generated random configurations were also used as initial configurations in ALSCAL. ALSCAL's random configurations are also based on a metric solution. All initial configurations yielded similar spatial representations and stress values and all suggested a 3-dimensional solution to be appropriate. A solution derived from a random initial configuration was chosen to represent the acts because its stress value for three dimensions was equal to that obtained for the solution derived from the metric initial configuration and the two solutions differed only slightly upon visual inspection. However, the solution derived from the random configuration correlated higher with a set of bipolar scales derived to describe the dimensions than did the solution derived from the metric configuration. Derivation of the bipolar scales will be discussed below.

Experiment 2

Purpose of Experiment 2. The second goal of multidimensional scaling is to interpret the dimensions after the appropriate dimensionality has been determined. In this experiment, interpreting the dimensions will describe the criteria subjects in Experiment 1 may have used when judging the similarity of acts, and thus may allow description of the important representations for the parking problem. Nonmetric MDS algorithms place the stimuli in the psychological space so that the distances between them best represent the distances defined by similarity judgments, but the coordinates of stimuli on the generated axes are arbitrary. The experimenter may rotate these axes to display the relationships between stimuli on more meaningful dimensions. One way to derive such axes is to subjectively determine a rotation which would reasonably represent meaningful values for stimuli. A less subjective method utilizes subjects' ratings of the stimuli on a set of bipolar scales to interpret the dimensions. The experimenter can derive bipolar scales to describe possible relationships between stimuli which may influence subjects' similarity judgments. In this study, the scales should describe the important criteria subjects might have used when judging the similarity of acts, and might be related to problem representation. A group of

subjects rates the stimulus items on each bipolar scale. The scale ratings are regressed against the stimulus coordinates derived from the scaling solution (Kruskal and Wish, 1978) to determine which scales correlate highest with the space derived from MDS. Scales having both a high multiple correlation with the stimulus coordinates and a high regression weight on a single dimension may be considered sufficient to describe the dimension. Experiment 2 was performed to obtain scale ratings for the 43 stimuli so the three derived dimensions could be objectively interpreted in the manner described above.

Method

Subjects. Subjects were fifty introductory psychology students who participated in the experiment to receive course credit.

Procedure. Subjects were seated in front of a CRT display controlled by a computer. Subjects read the same version of the Parking problem shown above and were asked to read the list of 43 stimuli. Each subject then rated 13 acts randomly chosen from the set of stimuli on each of 12 experimenter-derived bipolar scales. The scales, which are shown in Table 2, can be classified according to one of four types of problem representations which might be employed. The first three scales represent generic strategies for solving any instance of the "shortage" problem. The next four scales represent strategies specific to the parking problem which are instances of the more general strategies seen above. The third set, containing one scale, describes a personal goal the decision maker might evaluate when comparing the similarity of a pair of acts.

The final set of scales was included to assess whether subjects evaluate acts according to dimensions related to the problem. The four "evaluative" scales measure the utilities of acts. If these scales are found to correlate highly with any of the dimensions derived from multidimensional scaling, it will suggest that subjects based their similarity judgments on the relative utilities of pairs of acts, rather than basing their similarity judgments on criteria which may be influenced by their representation of the problem.

Table 2
12 bipolar scales used in Experiment 2

Generic strategies	
Uses current space more effectively	Doesn't use current space more effectively
Will increase amount of space available	Won't increase amount of space available
Reduces demand for space	Doesn't reduce demand for space
Specific strategies	
Requires building new facilities	Doesn't require building new facilities
Changes current parking priorities	Doesn't change current parking priorities
Involves alternate forms of transportation	Doesn't involve alternate forms of transportation
Involves rescheduling activities	Doesn't involve rescheduling activities
Personal goal	
Will restrict me	Won't restrict me
Evaluative dimensions	
Seems feasible	Doesn't seem feasible
Will cost a lot	Won't cost much
Seems fair	Doesn't seem fair
Will be protested	Won't be protested

The scales on which subjects rated the acts ranged from 1 to 10 with the leftmost description of the scale appearing under the number "1" and the rightmost description of the scale appearing under the number "10".

The act to be rated was displayed at the top of the screen, and the bipolar scale was displayed below it. The cursor was initially positioned at the center of the scale. Subjects read an act then rated it on a bipolar scale by moving the cursor of the CRT terminal right or left along the scale using one of two keys on the keyboard. The judgment could be modified until the subject was satisfied. Pressing another key recorded the subjects' scale rating. Subjects evaluated each act on all 12 scales before moving to another. However, the order in which the

scales were presented to a subject was random for each act.

<u>Analysis.</u> Approximately 16 ratings were obtained for each act on each scale. The scale ratings were averaged over subjects to yield a matrix of group scale ratings for all acts. Multivariate multiple regression was then used to regress the group scale ratings for each act on the acts' coordinates in the 3-dimensional act space to determine whether any scale could be predicted by the stimulus coordinates. As mentioned above, two criteria must be met before a scale is considered sufficient to describe a dimension. The multiple correlation between the scale and the stimulus coordinates must be high (or at least significantly different from zero) and a scale's regression weight on a single dimension must be high (Kruskal and Wish, 1978). Table 3 shows the multiple correlations between the scales and the stimulus coordinates and also the direction cosines which are regression weights normalized so that their sum of squared values equals 1. A direction cosine represents the cosine of the angle between an axis generated by the multidimensional scaling program and the dimension defined by each scale. A high direction cosine on a dimension means that the angle between a scale and the axis is small, suggesting a good fit.

Four scales seemed to best describe the three dimensions. Dimension 1 seems to be related to "involves alternate forms of transportation". This scale allows the simplest interpretation of the dimension because the multiple correlation is high (the squared multiple correlation=.709) and the direction cosine associated with Dimension 1 is also high.

Dimension 2 is not as easily interpreted. However, two somewhat overlapping scales, "changes current parking priorities" and "involves rescheduling activities" seem to describe the dimension fairly well. The multiple correlations between both scales and the stimulus coordinates are fairly high, but the direction cosines are only moderately high. Consideration of the qualities shared by the two scales may suggest a meaningful interpretation of Dimension 2 to the reader. The two scales accounted for more variance than any other scale in describing Dimension 2, so they were retained.

Table 3
Multiple correlations and direction cosines
between the 12 bipolar scales and the 3 generated dimensions

Scale	R	Direction cosines for Dim. 1	Dim. 2	Dim. 3
Specific strategies				
Involves alternate forms of transportation	.842*	.911**	.310	-.271
Involves rescheduling activities	.762*	.616	.758	.216
Changes current priorities	.686*	-.279	.767	.577
Requires building new facilities	.666*	-.323	.016	-.946
Generic strategies				
Will increase amount of space available	.589*	-.497	.310	-.809
Reduces demand for space	.550	.008	.558	-.830
Uses current space more effectively	.463	.460	.457	.761
Personal goals				
Will restrict me	.391	.921	.073	.383
Evaluative dimensions				
Will be protested	.635*	-.370	.631	.682
Will cost a lot	.580	-.235	.095	-.967
Seems fair	.463	.354	-.496	-.792
Seems feasible	.156	.138	.744	-.658

*Starred multiple correlations were significantly different from 0 at alpha < .001.

**A scale was used to describe a dimension if its corresponding direction cosine is underlined.

Dimension 3 appears to be related to the scale "requires building new facilities". The direction cosine for this scale was the highest observed, -.946, but the multiple correlation was fairly low. This scale describes Dimension 3 better than any others used; however, one should avoid interpreting the scale description literally because of the low multiple correlation.

The scales "will be protested" and "will increase amount of available space" had

multiple correlations which were significant at the .001 level of significance. However, "will be protested" was not used to describe a dimension because it did not have a high direction cosine on a single scale. The scale "will increase amount of space available" might be used to describe Dimension 3 because its direction cosine for Dimension 3 was .803. "Will increase the amount of space available" has a correlation of .63 ($p < .001$) with the scale "requires building new facilities" which makes sense because building new facilities would involve increasing the amount of space available for parking. However, because it has a relatively low multiple correlation (the squared multiple correlation=.347) with the stimulus coordinates, "will increase the amount of space available" was not used to describe Dimension 3.

The scales chosen to describe the dimensions derived from the multidimensional scaling solution are important because they suggest that subjects compared the similarity of act solutions according to specific strategies for solving the problem which might be implemented, rather than using personal goals or evaluative dimensions, such as the acts' relative cost or potential benefit to the university. The regression analysis suggests that subjects did not employ the personal goal "will restrict me" or the evaluative dimensions such as "seems fair", "will cost a lot", "seems feasible", and "will be protested" when comparing the similarity of pairs of acts.

The labels which best describe the three dimensions may represent alternative ways of interpreting the parking problem. The dimensions which best accounted for the subjects' judgments of similarity seemed to involve specific strategies for solving the problem which appear to be concrete examples of the generic strategies discussed in the introduction for solving a more general shortage problem. The parking problem is an example of a shortage of a commodity; in this case the commodity is parking spaces. Building new facilities is one way to obtain a larger supply of parking spaces. Using alternative forms of transportation should reduce demand for parking spaces. Changing priorities and rescheduling activities use the current supply of parking spaces more effectively. The relatively small multiple correlations between the stimulus coordinates and the generic strategies for solving a shortage problem suggest that generic strategies did not describe any of the dimensions well. Perhaps subjects made concrete comparisons when judging the

similarity of acts and did not think in general terms. This interpretation is consistent with Nisbett, Borgida, Crandall and Reed's (1976) finding that subjects attend more to concrete than to abstract information.

Examining the correlations between the bipolar scales also suggests that the subjects in some cases did not see the relationship between the specific strategies and the more generic strategies. Subjects' ratings of acts on the scale "involves building new facilities" had a correlation of .63 (p < .001) with the scale "will increase amount of space available". However, the correlation between the ratings for "uses current space more effectively" and ratings on the two scales defining Dimension 2, "involves rescheduling activities" and "changes current priorities" were only .33 (p < .05) and .32 (p < .05), respectively. Also, "involves alternate forms of transportation" and "reduces demand for space" correlated only .20, (p > .05).

Graphic display of the three dimensional solution. Three dimensional displays of the acts on the derived dimensions can be seen in Figures 2 - 4. The dimensions on which acts are displayed are depicted as being orthogonal to each other, though they were really nonorthogonal. To correct for this distortion, the stimulus coordinates were transformed so that the original locations were projected onto orthogonal axes. The three figures describe the same act space, but each places the observer at a different perspective for examining the space. Each of the figures allows examination of a different dimension or shows a viewpoint which cannot be seen from another angle. The dimensions are labelled so that it is possible to observe which acts have positions relatively close to the extremes of a particular axis.

Figure 2 displays Dimension 1 (involves alternate forms of transportation) most clearly. Acts which were perceived as involving alternate forms of transportation include numbers 29, "Encourage students to stop air pollution by not driving", 30, "Counsel students about the parking problem", 37, "form cycling clubs for commuters", 5, "advertise the advantages of riding a bicycle or motorcycle", 14, "build bicycle paths", 15, "provide more security for bicycles", 11, "encourage people not to bring cars", 12, "provide incentives for people participating in carpools", 28, "the university could set up a carpool", 4, "encourage carpooling by commuters", 36, "improve the trolley and Campus Area Rapid Transit systems",

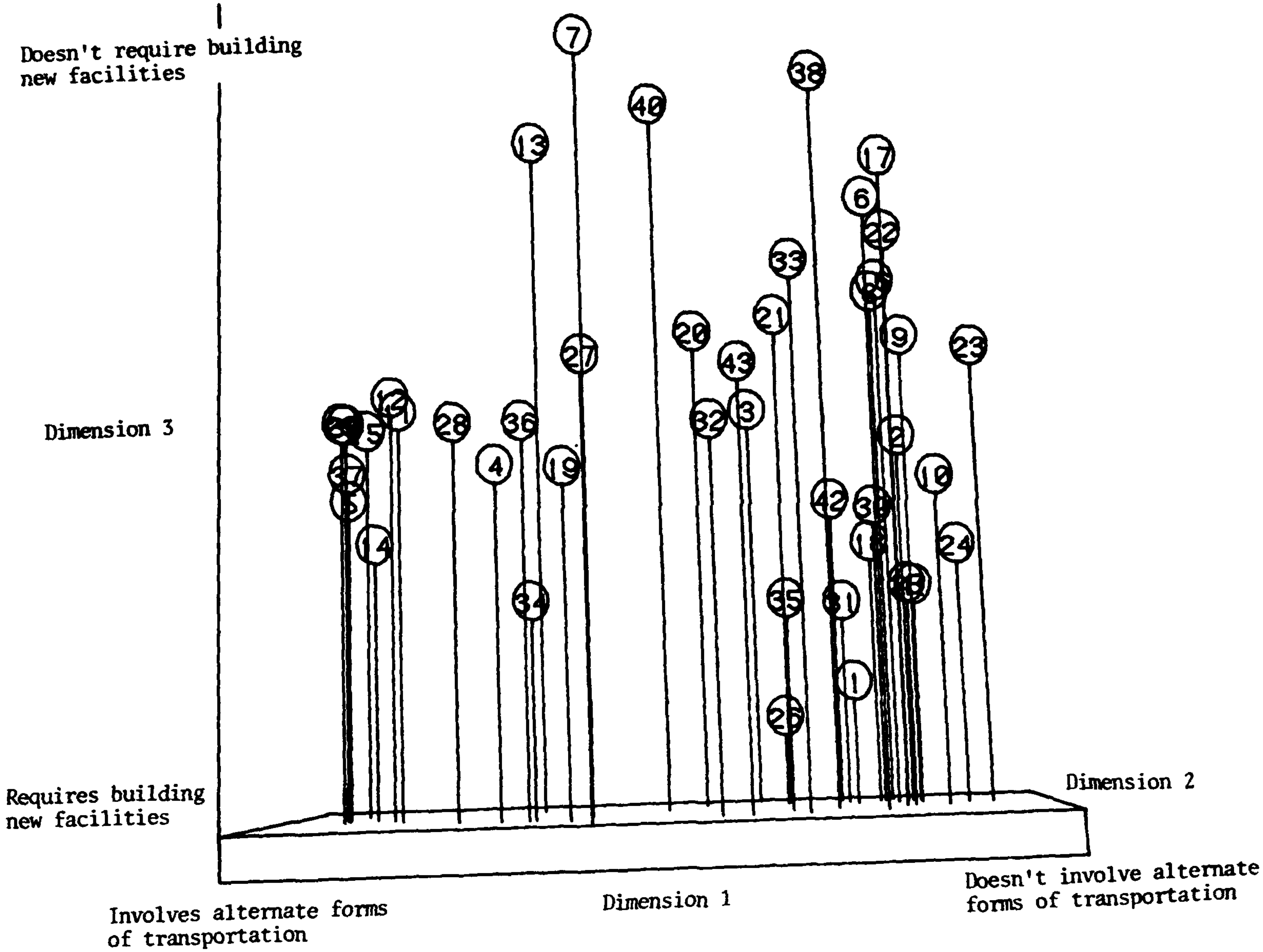

Figure 2. Three dimensional act space (perspective 1)

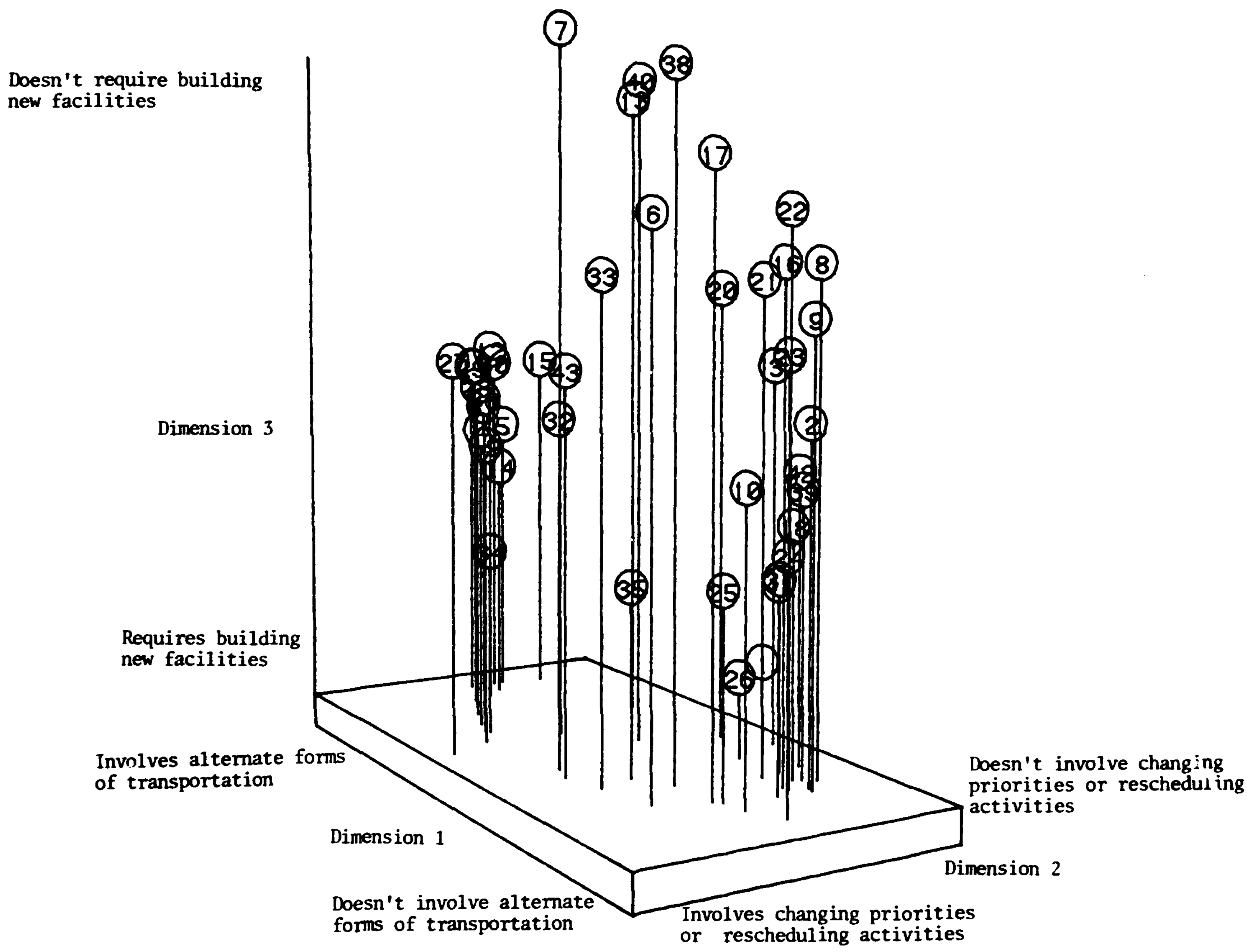

Figure 3. Three dimensional act space (perspective 2)

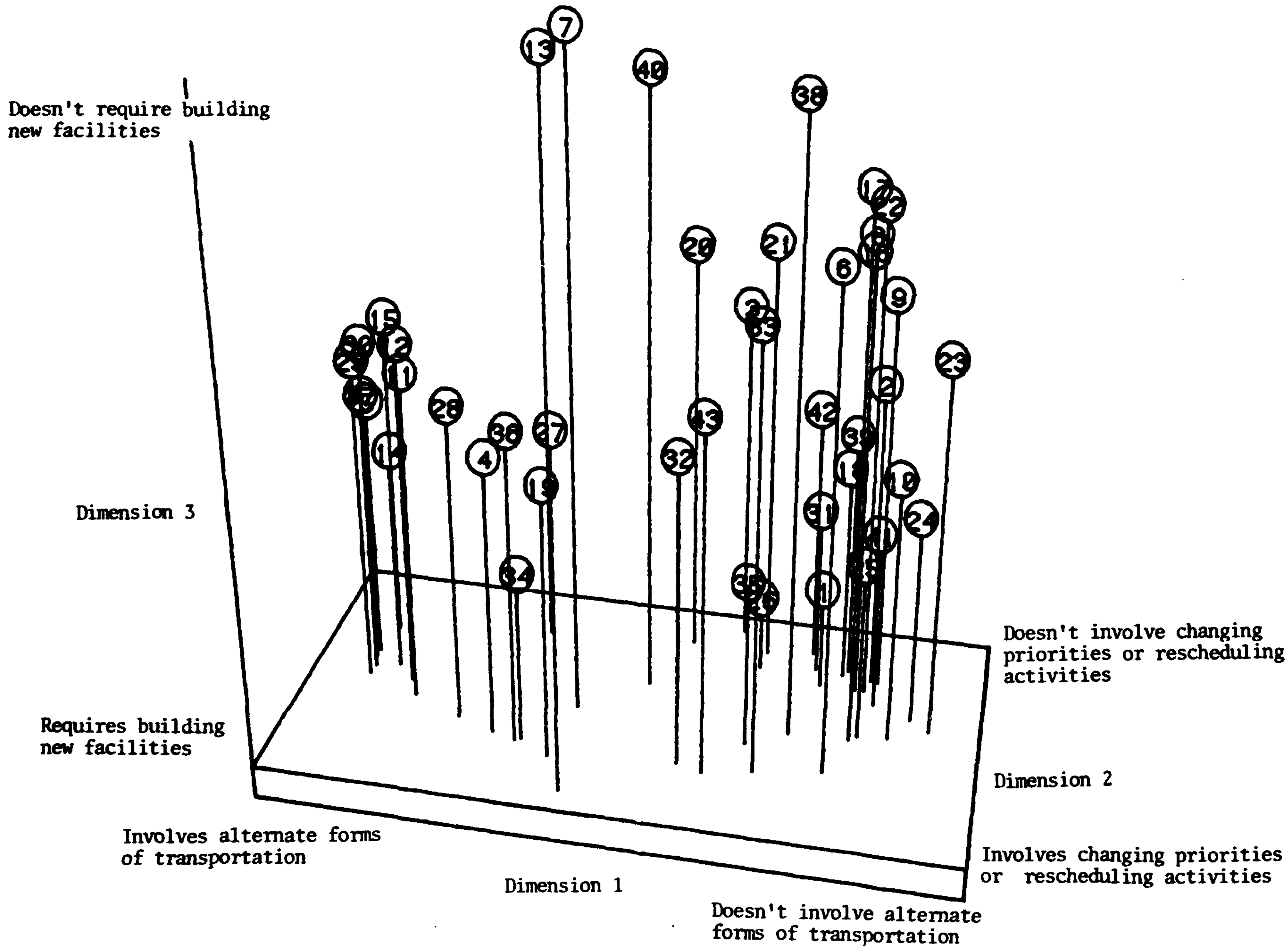

Figure 4. Three dimensional act space (perspective 3)

19, "set up a rapid transit system to operate during school hours", and 34, "have a bus system from campus to shopping malls". Figure 3 shows particularly clearly that these acts are distinct from the others. These acts can be meaningfully interpreted as involving or suggesting the use of alternate transportation forms.

Acts which were perceived as not involving alternate forms of transportation include 23, "Let people park on the South Oval", 10, "expand the parking facility at the Lloyd Noble Center", 24, "build new lot by 'jock' dorms", 25, "build another lot like the one at the Lloyd Noble Center", 41, "search for an area around campus to create more parking", 2, "put signs up on the streets around campus so they can be used for parking", 9, "use extra areas around fraternity houses for overflow parking", and many others. Subjects may have thought that planning to provide new parking areas would discourage using alternate forms of transportation.

Figures 3 and 4 are both useful for examining the location of acts on Dimension 2 (related to changing parking priorities and rescheduling activities). Acts perceived as involving rescheduling activities or changing priorities include 27, "ask commuters to carpool", 19, "set up rapid transit system to operate during school hours", 34, "have bus system from campus to shopping malls", 36, "improve the trolley and Campus Area Rapid Transit systems", 43, "Make all commuter parking at the Lloyd Noble Center", 26, "Build new buildings as high rises, put parking around the bottom", and 6, "Make faculty and staff park at the Lloyd Noble Center (large parking facility at basketball stadium) and ride the trolley to campus" and others. Acts perceived as involving changing priorities or rescheduling activities would cause drivers to change some of their parking habits.

Acts perceived as involving no changes in priorities or no rescheduling of activities include 3, "repaint lines in the parking lots to make spaces smaller", 20, "raise parking fees and improve lots currently used", 42, "remove 30 minute meters from parking lots", 21, "put more small car spaces in student lots", 13, "impound cars which don't have the proper stickers", 15, "provide bicycle security", and many others. These acts might change the amount of space available or reduce demand for space without influencing peoples' parking habits.

Figure 2 is probably most useful for examining Dimension 3. In some respects

Dimension 3 is the inverse of Dimension 1. Dimension 3 required building new facilities. Acts which were perceived as requiring building new facilities include 26, "build new buildings as high rises so parking can be placed around the bottom", 1, "build high rise parking garage", 34, "have bus system running from campus to shopping malls", 35, "build lots at different locations around town and shuttle in from there", 31, "arrange for parking at Stubbeman Village", 25, "build another lot like the one at the Lloyd Noble Center", 41, "search for an area around campus instead of building new buildings". The interpretation of this end of the dimension seems to include investing in systems that might alleviate the parking problem as well as building structures to house more cars. However, recall that the multiple correlation was low for Dimension 3 so the description "involves building new facilities" should only be considered a guide to interpreting the dimension.

Acts which were not perceived as involving building new facilities include 7, "Have more afternoon and evening courses available", 38, "staff parking needs more closely allotted times", 40, "Make fraternity and sorority members park at their houses", 13, "impound cars without proper parking stickers", 17, "make some faculty parking student parking", and 6, "make faculty, staff park at the Lloyd Noble center". Subjects may have thought that regulating current parking facilities would reduce the need for building new facilities by providing more space.

The following section describes how hierarchical cluster analysis was applied to the similarity judgments collected in Experiment 1. Hierarchical cluster analysis was used to analyze these data because it provides an interpretation of the subjects' criteria for judging the similarity of acts which complements the dimensional interpretation.

Deriving neighborhoods in the act space with hierarchical cluster analysis. Cluster analysis is a numerical method for partitioning stimuli into homogeneous groups. While the multidimensional scaling procedure described above was useful for describing relationships between stimuli which lay at opposite extremes of semantic dimensions, cluster analysis is useful for describing relationships between stimuli which are very close together (Kruskal, 1977). Hierarchical

cluster analysis creates a tree structure which displays the level of similarity at which stimuli are assigned to a cluster. Very similar stimuli join together at low similarity values. These clusters resemble "twigs". Relatively dissimilar items join together much later at high similarity values. These clusters resemble a "limb". The tree can be cut at a specified level of similarity to yield a set of distinct, nonoverlapping clusters. The resulting clusters can be considered as forming boundaries which define regions in a multidimensional space containing very similar stimuli (Bailey, 1974). Interpreting these regions may provide a description of the acts which complements the interpretation of the dimensions derived from MDS.

Cluster analysis techniques assume an underlying "mixture model" which specifies that stimuli employed in the analysis came from several populations, each having a distinct probability distribution (Wolfe, 1970). The major purpose of cluster analysis is to identify the number of distributions represented and to correctly classify stimuli belonging to one of the underlying distributions.

Many clustering algorithms are available which are based on different criteria for admitting an object to a cluster. Most algorithms yield different solutions because they change the boundaries drawn in the multidimensional space which define the clusters. Cluster analysis algorithms employ distance estimates like the judgments of similarity obtained in Experiment 1 to create the clusters. Agglomerative cluster analysis techniques (Gower, 1967), begin with $\underline{n}$ clusters corresponding to the complete set of stimuli and combine the two most similar clusters into a single cluster. This process continues until all stimuli are combined into a single cluster. Divisive techniques begin with a single cluster containing all stimuli and divide it into smaller clusters, until eventually all stimuli belong to separate clusters.

Another way clustering methods can be distinguished depends on whether they allow stimuli to be a member of more than one group. Stimuli clustered with hierarchical clustering techniques belong to nonoverlapping groups. Additive (nonhierarchical) clustering methods are also available which allow stimuli to be clustered into more than one major group. Hierarchical cluster analysis techniques yield a tree structure whose major limbs contain large groupings of stimuli and whose minor limbs contain subsets of the stimuli contained within the

major limbs.

Several methods of hierarchical cluster analysis are available that employ different criteria to determine into which group the stimuli will fall. Sokal & Sneath (1963) described the three major types as Single Linkage (also known as "minimum method" or "connectedness method"), Complete Linkage (also known as "maximum method" or "diameter method") and Average Linkage (also called UPGMA or "Unweighted Pair Group Method using Arithmetic Averages). The three methods differ in their criteria for admitting a new member to a cluster. Single Linkage cluster analysis admits a new member to a cluster if the correlation between the object and any other member of the cluster is greater than the correlation between the object and every object not in the cluster. Single linkage cluster analysis often produces "chaining"; an object may be similar to only one other member of the cluster. Complete Linkage cluster analysis admits a new object to a cluster only if the object is more highly correlated with every member of the cluster than any object outside the cluster. Complete Linkage solutions produce compact clusters. Average Linkage cluster analysis admits a new object to a cluster if the object does not lower the average similarity of the objects within a cluster more than a specified amount. This method represents a compromise between single and complete linkage methods.

Edelbrock (1979) found the average linkage algorithm to be more accurate than either single or complete linkage in correctly resolving a mixture of multivariate normal populations. However, he also found the accuracy of any hierarchical techniques dropped as the level of coverage increased; when a clustering algorithm is forced to incorporate increasingly less-similar clusters into the hierarchy, the solution is more likely to be inaccurate. This result supports the common assumption that cluster analysis best describes the relationships between very similar stimuli while multidimensional scaling best describes the relationships between very dissimilar stimuli (Kruskal, 1977).

The two major goals associated with using hierarchical cluster analysis are to derive a stable solution and to determine the optimal number of clusters. A stable solution is one which is consistent regardless of the type of clustering algorithm used to derive it. One way to test the stability of a solution is to replicate it using more than one type of linkage (Blashfield, 1979). The optimal

number of clusters is that number which best distinguishes the distinct populations represented in the sample.

Single, complete and average linkage solutions were computed for the similarity judgments obtained in Experiment 1 using the TAXON procedure in the NT-SYS statistical package (Rohlf, Kishpaugh and Kirk, 1979). The three types of linkages yielded many small clusters which contained the same acts. However, the three types of linkages differed in the way they combined the small clusters into higher-order clusters. This result is not unusual because clustering algorithms are typically less accurate when combining more dissimilar items into clusters.

Figures 5 and 6 display the trees derived from the average and complete linkage solutions, respectively. Both tree structures are presented so that the reader may compare them to assess the stability of the clustering solution. The single linkage solution was not displayed because it was not very meaningful. As mentioned above, single linkage cluster analysis is rarely used in psychological research because the clusters it produces are often chained. Although small clusters may be meaningful, the larger clusters created with single linkage methods by combining smaller clusters are less meaningful than those created with either average or complete linkage.

Because the average and complete linkage methods clustered many small groups of stimuli identically, the author felt the solution was sufficiently stable to usefully describe the neighborhoods contained in the act space. Although the average and complete linkage solutions were very similar, the average linkage solution was chosen as the method which best described the hierarchical relationships between acts. The average linkage solution was chosen because it appeared to be more meaningful. As an illustration of this point, the complete linkage solution classified act #7, "have more of a selection of afternoon and evening courses available", with acts which encouraged carpooling. Act #13, "impound cars without the proper parking stickers", was classified with acts suggesting that a rapid transit system be implemented. The average linkage solution, which classified both acts as distinct from the remaining acts, seemed to provide a more meaningful interpretation. The average linkage solution was the only solution retained for later analyses.

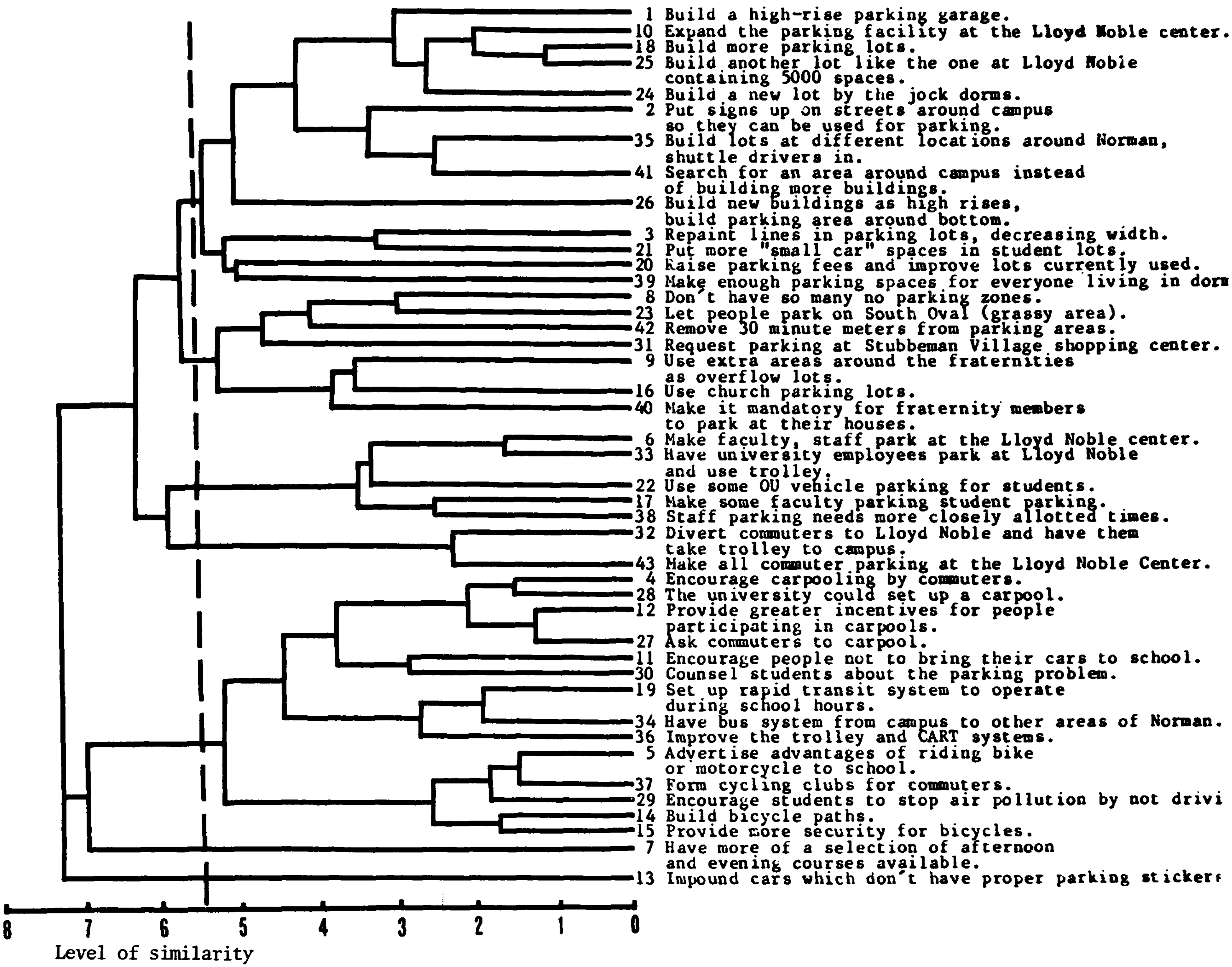

Figure 5. Average linkage cluster analysis tree

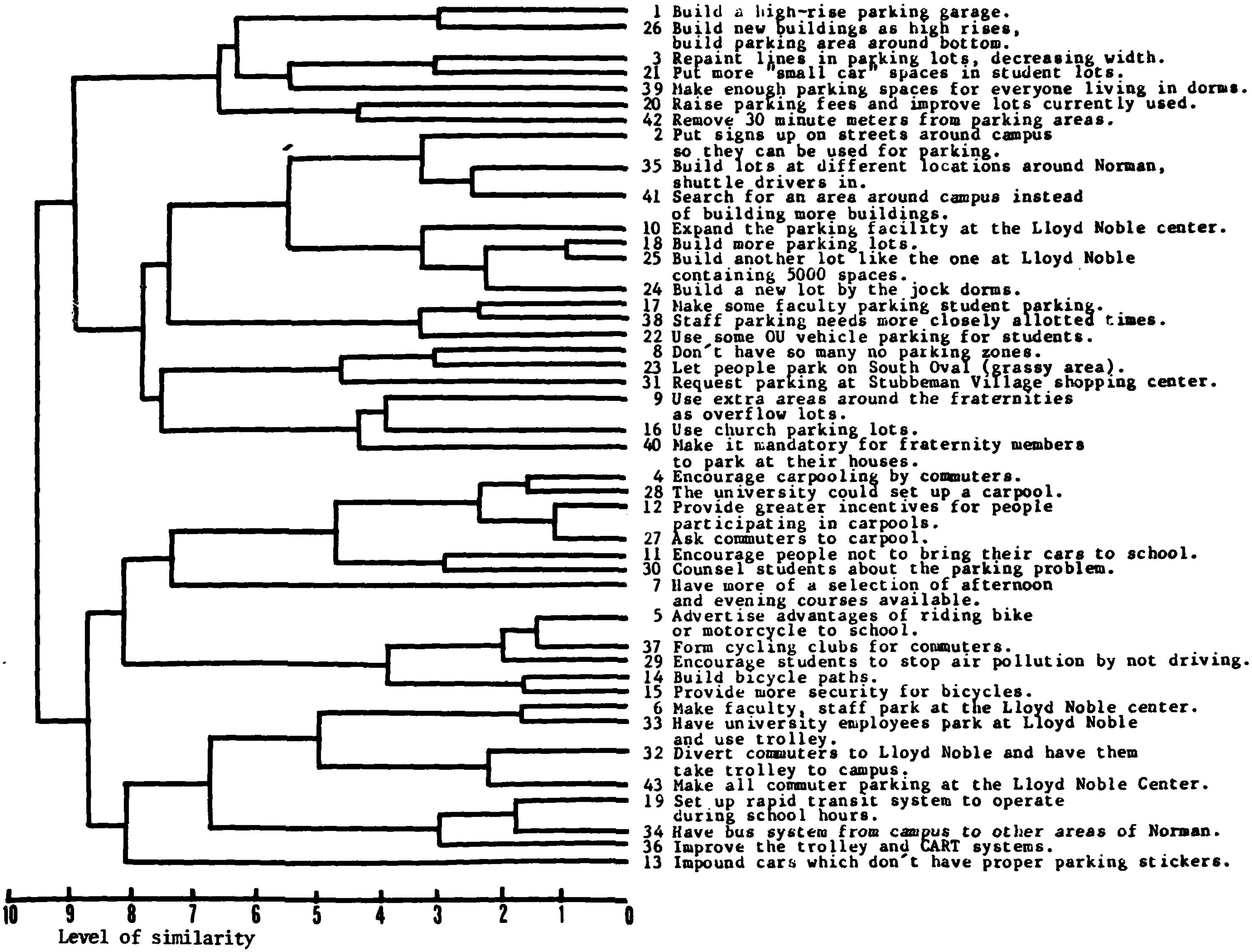

Figure 6. Complete linkage cluster analysis tree

Table 4
Tree derived from Average linkage cluster analysis

1. Create more parking space.
    1.1 Build parking structures.
        1.1.1 (1) Build high rise.
    1.2 Build more parking lots.
        1.2.1 (10) Expand Lloyd Noble parking facility.
        1.2.2 (18) Build more lots.
        1.2.3 (25) Build another lot like Lloyd Noble.
        1.2.4 (24) Build a new lot by the jock dorms.
    1.3 Creative uses of space.
        1.3.1 (2) Put parking signs up on streets around campus to create space.
        1.3.2 (35) Build lots in different locations around Norman, shuttle in.
        1.3.3 (41) Look for area currently available instead of building more buildings.
    1.4 Plan parking areas more closely.
        1.4.1 (26) Build new buildings as high rises, park around bottom.
    1.5 Use current space more effectively.
        1.5.1 (3) Repaint lines, decrease width of spaces.
        1.5.2 (21) Put more small car parking in student section.
        1.5.3 (20) Raise parking fees to improve, expand lots.
        1.5.4 (39) Make enough spaces for everyone living in dorm.
2. Make better use of available areas.
    2.1 Remove current restrictions on areas used for parking.
        2.1.1 (8) Don't have so many no parking zones.
        2.1.2 (23) Let people park on the South Oval.
        2.1.3 (42) Remove 30 minute meters.
        2.1.4 (31) Request parking at Stubbeman Village.
    2.2 Use areas around campus.
        2.2.1 (9) Use areas around frats for overflow parking.
        2.2.2 (16) Use church lots.
        2.2.3 (40) Make frat members park at their own houses.
3. Change current parking priorities for faculty/staff.
    3.1 Eliminate faculty, staff parking space.
        3.1.1 (6) Mandatory parking for faculty, staff at Lloyd Noble.
        3.1.2 (33) Have employees park at Lloyd Noble, use trolley.
        3.1.3 (22) Use OU vehicle parking for students.
    3.2 Regulate faculty, staff space.
        3.2.1 (17) Make some faculty parking student parking
        3.2.2 (38) Staff parking needs more closely allotted times.
4. Remove commuters' privileges.
        4.1.1 (32) Have commuters park at Lloyd Noble, use trolley.
        4.2.2 (43) Make all commuter parking at Lloyd Noble.
5. Encourage use of alternate forms of transportation.
    5.1 Encourage carpooling.
        5.1.1 (4) Encourage carpooling by commuters.
        5.1.2 (28) OU could organize a carpool.
    5.2 Provide incentives for carpooling
        5.2.1 (12) Provide greater incentives for carpooling.
        5.2.2 (27) Ask commuters to carpool.
    5.3 Appeal to good judgment.
        5.3.1 (11) Encourage people not to bring cars.
        5.3.2 (30) Counsel students about parking problem.
    5.4 Mass transit
        5.4.1 (19) Set up rapid transit system during school hours.
        5.4.2 (34) Employ bus system from campus to shopping malls.
        5.4.3 (36) Improve trolley and CART systems.
    5.5 Encourage use of bicycles, motorcycles.
        5.5.1 (5) Advertise the advantage of riding a bike, motorcycle.
        5.5.2 (37) Form cycling clubs for commuters.
        5.5.3 (29) Encourage students to stop pollution by riding bikes.
    5.6 Make individual transportation safer.
        5.6.1 (14) Build bike paths.
        5.6.2 (15) Provide more security for bikes.
6. (7) Have more selection of afternoon, evening courses available.
7. (13) Impound cars without stickers.

The second problem in using hierarchical cluster analysis is to determine the optimal number of clusters. The number of clusters is determined by cutting the tree structure at a certain level. Everitt (1979) proposed that no statistical technique can objectively determine where to cut the tree so the optimal number of clusters is identified. The experimenter typically examines the tree structure and determines at which level the tree can be cut to provide the most meaningful set of clusters. By cutting the average linkage tree at the highest similarity level possible, two "primary" limbs may be observed. These primary limbs can be described as "increase amount of parking space" and "use alternate forms of transportation". Acts 7, "have more afternoon and evening courses available", and 13, "impound cars without stickers" seem to be an exception and were classified as outliers in the solution.

Several other meaningful distinctions between acts can be made by cutting the tree at a lower similarity level. In Figure 5, the dotted line extending vertically through the tree shows where the tree was finally cut. Table 4 displays the average linkage cluster analysis solution determined by cutting the tree at the level described by the dotted line in Figure 5. The reader should keep in mind that the number of clusters was determined subjectively and may choose to examine different similarity levels at which the tree might be cut to create a different number of clusters.

Four major limbs were derived from the primary limb "Increase amount of space available" for the average linkage tree. These were 1, "Create more parking space", 2, "Make better use of available areas", 3, "Change current parking priorities for faculty/staff", and 4, "Remove commuter privileges". The acts contained in the four limbs can be seen in Table 4. The number appearing in parentheses before each act refers to the identification number of the act listed in Table 1.

The clusters described by the limbs in Table 4 may also be considered boundaries for regions of the multidimensional space shown in Figures 3 and 4. Many of the acts in Limb 1, "create more space", can be found in the lower right region of the act space shown in Figures 3 and 4. Most of the acts in Limb 2, "make better

use of available areas", can be found in the upper right area of Figures 3 and 4. The acts in Limb 3, "change current parking priorities" can be seen primarily in the upper middle-to-right portion of the space, while Limb 4, "remove commuters' privileges" contains two acts located in the central portion of the graph. Although the acts in each cluster are usually located close to other members of the same cluster in the multidimensional space, the regions of the space defined by the clusters are not distinct. The exception is Limb 5, which involved the use of alternate forms of transportation.

The primary limb involving the use of alternate forms of transportation was not divisible into major limbs as was the primary limb involving increasing the amount of space. However, several branches within the alternate transportation limb may be distinguished: carpooling, use of mass transportation, use of individual transportation, etc. Examination of Figure 3 illustrates that considering the branch classifications to be distinct major limbs is inappropriate because the acts in Limb 5 form a very homogeneous cluster in the multidimensional space which is distinct from the remaining acts.

The average linkage solution left two acts as outliers which did not seem to fit into any other category. These acts were 7, "make more afternoon and evening courses available" and 13, "impound cars without stickers". Figure 4 clearly shows that these acts are distinct from the remaining acts in the multidimensional space and thus can be reasonably placed in different limbs.

The cluster analysis solution provides an interpretation of the act space which complements the multidimensional scaling solution. The seven limbs derived from cluster analysis define regions of the multidimensional space containing acts which resemble each other more than they resemble acts in any other cluster. Just as the dimensions of the multidimensional space seemed to involve specific strategies for solving the parking problem, the regions in the space defined by cluster analysis can also be described as involving specific problem solving strategies. Support for this interpretation exists because each limb or region defined by the average linkage solution contains a set of acts whose similarity with each other is defined by the specific operations required to implement them. For example, the acts in Limb 1 require making physical changes to the university or surrounding areas to increase the amount of space available. The acts in Limb

2 increase the amount of space available by removing parking restrictions rather than making physical changes to the university. The acts in Limb 3 require increasing the restrictions placed on the faculty and staff to increase the number of parking places available to students. The acts in Limb 4 regulate commuters' parking privileges so more space will be available to others. The acts in Limb 5 encourage the use of alternate forms of transportation. The branches within this limb describe different forms of alternate transportation which might be implemented.

Limbs 6 and 7 necessarily involve specific solutions to the problem because each limb contains only one act. However, in order for additional acts to be placed in limb 6, they must involve rescheduling activities, while additional acts placed in Limb 7 would involve enforcing current traffic regulations. Thus both the multidimensional scaling analysis and cluster analysis seem to suggest that the similarities between acts are defined in terms of specific strategies which might be used to solve the parking problem.

Summary and conclusions.

Before discussing the implications of the current study, a summary of the significant findings seems warranted. This study described several important and distinct dimensions decision makers used when judging the similarity of acts suggested to solve a problem. Because act solutions are responses typically emitted when encountering a decision problem and similarity judgments should be based on a decision makers' interpretation of the problem, we believe that these results may also describe the problem representations considered important by a group of people.

Similarity judgments were obtained for 43 acts suggested to solve the OU parking problem and submitted to a nonmetric multidimensional scaling program which yielded a 3-dimensional solution. A regression analysis was performed to objectively identify the dimensions obtained from multidimensional scaling. The three dimensions were described as involving "alternate forms of transportation", "changing priorities and scheduling", and "building new facilities". The similarity judgments were next submitted to a hierarchical cluster analysis. The average linkage solution yielded two major clusters: increasing the amount of

parking space and using alternate forms of transportation. All but two acts, number 7, "have more afternoon and evening courses available", and 13, "impound cars without the proper stickers", fit into these categories. The two major clusters and the two outlying acts were further decomposed to yield seven major limbs of an act tree: "create more space", "make better use of available areas", "change current parking priorities for faculty/staff", "remove commuters' privileges", "encourage the use of alternate forms of transportation", "have more afternoon and evening courses available", and "impound cars without the proper stickers".

Both the multidimensional scaling and cluster analysis solutions yielded descriptions of the act space which seemed to entail specific strategies that might be used to solve the parking problem. The cluster analysis solution decomposed the concrete strategies describing the dimensions in the multidimensional space into even more specific strategies dealing with specific users of the parking facilities (commuters and faculty/staff) and specific ways of creating more space (building more or using current space more effectively). The cluster analysis solution also provided evidence that two additional acts, "have more afternoon and evening courses available" and "impound cars without the proper stickers" were distinct from the other clusters and thus represented potential unique strategies for solving the problem.

The multidimensional scaling and cluster analysis solutions are complementary because both seem to suggest that more than one problem representation may be salient to at least a subset of the total group of subjects used in the study. This result does not imply that individual decision makers necessarily employ more than one problem representation at a time; subsequent research must be performed to investigate how individuals may employ the representations described in the current study. However, this study suggests that alternative problem representations are available to decision makers. On the basis of these results, it is possible to speculate that decision makers may interpret a problem using only one of the possible problem representations identified here. This might lead to accessing only part of the information relevant to the problem, and to the generation of an incomplete set of acts. Problem representation may thus influence which acts are or are not generated.

A second result obtained in this study was that both the MDS and cluster analysis suggested that problem representation should be conceptualized as involving specific problem-solving strategies rather than generic strategies for solving the problem, personal goals or evaluative criteria. The bipolar scales used in Experiment 2 which had the highest correlation with the multidimensional scaling solution were related to specific problem solving strategies. The specificity of the sets of acts contained in each limb of the cluster analysis solution also suggests this conclusion is appropriate.

In real-world problems, the problem state, the goal state and procedures to move from one to the other are not well-defined. The results obtained in this study suggest that although real-world decision problems are unstructured, the important ways decision makers may represent a problem can be described using a limited number of dimensions. Further research on the processes involved in generating act solutions for real-world problems may be performed to assess individuals' capabilities for employing one or more of the important dimensions described here.

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Washington, D.C. 20380

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Naval Material Command
NAVMAT 0722 - Rm. 508
800 North Quincy Street
Arlington, VA 22217

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Human Factors Programs
NAVAIR 340F
Washington, D.C. 20361

CDR Robert Biersner
Naval Medical R & D Command
Code 44
Naval Medical Center
Bethesda, MD 20014

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Behavioral Sciences Department
Naval Medical Research Institute
Bethesda, MD 20014

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Human Factors Engineering Branch
Submarine Medical Research Lab
Naval Submarine Base
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Code L5
Naval Aerospace Medical Research Lab
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Human Factors Engineering Division
Naval Air Development
Warminster, PA 18974

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Human Factors Branch
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Naval Weapons Center
China Lake, CA 93555

Human Factors Engineering Branch
Code 1226
Pacific Missile Test Center
Point Mugu, CA 93042

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5001 Eisenhower Avenue
Alexandria, VA 22333

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U.S. Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

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Human Engineering Division
USAF AMRL/HES
Wright-Patterson AFB, OH 45433

Dr. Earl Alluisi
Chief Scientist
AFHRL/CCN
Brooks AFB, TX 78235

Dr. Kenneth Gardner
Applied Psychology Unit
Admiralty Marine Technology
Establishment
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Dr. A. D. Beddeley
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Dr. Judith Daly
System Sciences Office
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Agency
1400 Wilson Blvd.
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Dr. Robert R. Mackie
Human Factors Research, Inc.
5775 Dawson Avenue
Goleta, CA 93017

Dr. Gary McClelland
Institute of Behavioral Sciences
University of Colorado
Boulder, CO 80309

Dr. Jesse Orlansky
Institute for Defense Analyses
400 Army-Navy Drive
Arlington, VA 22202

Dr. T. B. Sheridan
Department of Mechanical Engineering
Massachusetts Institute of Technology
Cambridge, MA 02139

Dr. Paul Slovic
Decision Research
1201 Oak Street
Eugene, OR 97401

Dr. Harry Snyder
Department of Industrial Engineering
Virginia Polytechnic Institute and
State University
Blacksburg, VA 24061

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Department of Psychology
Stanford University
Stanford, CA 94305

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Oceanautics, Inc.
422 6th Street
Annapolis, MD 21403

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NAS - National Research Council
2101 Constitution Ave., N.W.
Washington, D.C. 20418

Dr. M. G. Samet
Perceptronics, Inc.
6271 Variel Avenue
Woodland Hills, CA 91364

Dr. Robert Williges
Human Factors Laboratory
Virginia Polytechnic Institute
and State University
130 Whittemore Hall
Blacksburg, VA 24061

Dr. Alphonse Chapanis
Department of Psychology
The Johns Hopkins University
Charles and 34th Streets
Baltimore, MD 21218

Dr. Ward Edwards
Director, Social Science Research
Institute
University of Southern California
Los Angeles, CA 90007

Dr. Kenneth Hammond
Institute of Behavioral Science
University of Colorado
Room 201
Boulder, CO 80309

Dr. James H. Howard, Jr.
Department of Psychology
Catholic University
Washington, D.C. 20064

Dr. William Howell
Department of Psychology
Rice University
Houston, TX 77001

Dr. Christopher Wickens
University of Illinois
Department of Psychology
Urbana, IL 61801

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Information Sciences Division
Bolt Beranek & Newman, Inc.
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Dr. Hillel Einhorn
University of Chicago
Graduate School of Business
1101 E. 58th Street
Chicago, IL 60637

Dr. John Payne
Duke University
Graduate School of Business
Administration
Durham, NC 27706

Dr. Baruch Fischhoff
Decision Research
1201 Oak Street
Eugene, OR 97401

Dr. Andrew P. Sage
University of Virginia
School of Engineering and Applied
Science
Charlottesville, VA 22901

Dr. Leonard Adelman
Decisions and Designs, Inc.
8400 Westpark Drive, Suite 600
P.O. Box 907
McLean, VA 22101

Dr. Lola Lopes
Department of Psychology
University of Wisconsin
Madison, WI 53706

Mr. Joseph G. Wohl
Alphatech, Inc.
3 New England Industrial Park
Burlington, MA 01803

Dr. Rex Brown
Decision Science Consortium
Suite 721
7700 Leesburg Pike
Falls Church, VA 22043

Dr. Wayne Zachary
Analytics, Inc.
2500 Maryland Road
Willow Grove, PA 19090

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